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November 4, 2003

Mr. Nabil S. Fayoumi
U. S. Environmental Protection Agency - Region 5
Superfund Division
77 West Jackson Boulevard (SR-6J)
Chicago, Illinois 60604-3590

**Re: Response to Comments on Workplan DNAPL Characterization and Remediation Study, Sauget Area 1
Sauget, Illinois**

Dear Mr. Fayoumi:

Attached is our Response to Comments received from the EPA in a letter dated October 15, 2003, on the revised Workplan, DNAPL Characterization and Remediation Study, Sauget Area 1, Sauget, Illinois.

This response to comments and the attached technical memorandum, "Technical Memorandum, Applicability of Uniform Concentration to Mass Ratio Assumption", addresses each comment from Laramide Environmental and EPA.

The DNAPL Characterization and Remediation Study is focused on collecting the information needed for i) estimation of the volume of DNAPL-affected material; ii) assessment of the ability to remove DNAPL from the aquifer matrix by treatment; iii) estimation of the removal efficiencies of various treatment technologies; and iv) determination of the presence of pooled DNAPL. These data will be used to determine if aggressive source treatment will make any meaningful difference in the time required to achieve ARAR's and, if so, the cost of such treatment.

This investigation was designed to ensure that we gather the type of information needed to support a Technical Impractability demonstration should the actual site conditions and the evaluation of remedial alternatives indicate that ARAR's cannot be met in a reasonable period of time. We request that the Agency notify us if it believes that the data we will be collecting during implementation of the Work Plan would not meet the data requirements for a TI determination by the Agency.

Please review this response and let me know if it is acceptable to you. If not, please let me know so that we may resolve any remaining issues. If you have any questions, please contact me at 314-674-6768.

Sincerely,

Solutia Inc.

Gary W. Vandiver
Project Coordinator

cc: Sandra Bron - IEPA
Ken Bardo - USEPA
Mike Coffey - USF&W
Tim Gouger – USACE
Walter Weinig – Laramide
Steven Schmidt - ExxonMobile
Joe Grana – Cerro Copper
Cathleen Bumb - Solutia
Linda Tape - Husch & Eppenberger
Richard Williams - Solutia
Bruce Yare – Solutia

1) **We appreciate the substantial revisions that have been made in this draft of the work plan. The revised work plan addresses the major focus areas presented in the January 9, 2003 letter from the United States Environmental Protection Agency (USEPA) to Solutia requesting the DNAPL characterization study.**

   RESPONSE: No response necessary.

2) **Section 2.0, Conceptual Site Model: The focus of this section on the high costs and possible impracticability of treating large volumes of DNAPL-contaminated fill and aquifer material is inappropriate for a work plan that is designed to address precisely these questions. This section of the work plan presents a Technical Impracticability (TI) waiver as nearly a foregone conclusion prior to any data collection or evaluation. While a TI waiver is one possible response to DNAPL contamination in Sauget Area 1, other responses are also possible and should not be dismissed so readily in the planning stages of this investigation. The DNAPL characterization study should be conducted in an unbiased, objective manner to develop the scientific and engineering data required to make a defensible evaluation of response actions. The Conceptual Site Model section of the work plan should reflect an objective evaluation of existing data without focusing on one particular response action.**

   RESPONSE: Section 2.0 Conceptual Site Model will be revised as shown below and incorporated verbatim into the Work Plan:

2.0 CONCEPTUAL SITE MODEL

DNAPL Distribution - An objective evaluation of existing data indicates that:

- Pooled DNAPL is or may be present in Sites G, H, I and/or L;
- DNAPL is or may be present as small, discreet blobs and/or ganglia in the unsaturated zone;
- DNAPL is or may be present as small, discreet blobs and/or ganglia in the saturated zone;
- Dissolved DNAPL is or may be present in the aquifer beneath and downgradient of Sites G, H, I and/or L; and
- Pooled DNAPL is or may be present at the alluvial aquifer/bedrock interface beneath or downslope of Sites G, H, I and/or L.

Sites G, H, I and L cover an area of 27.55 acres broken down as follows: Site G - 4.33 Acres, Site H - 5.22 Acres, Site I - 16.88 Acres and Site L - 1.12 Acres. With depth to bedrock of somewhere between 100 and 120 feet at these former disposal areas, the potential volume of DNAPL-containing waste and soil is unknown but could be as much as approximately 4.4 million cubic yards (i.e., 1.0 million cubic yards of waste and 3.4 million cubic yards of underlying aquifer materials). Figure 4 shows the known or suspected vertical distribution of DNAPL within and beneath the Sauget Area 1 source areas.

Human Health and Environmental Protection - Groundwater usage in the Villages of Sauget and Cahokia is prohibited by ordinance. There is no evidence that anyone in Sauget or Cahokia receives drinking water from the groundwater. In fact, there is a public source of drinking water from an intake of the Mississippi River far downstream of the impacted sites. Consequently, there is no immediate threat to public health due to the presence of DNAPL associated with Sites G, H, I, and L. There is a potential for harm if workers were exposed to DNAPL in the course of intrusive work during construction activities. However, this potential exposure can be controlled by implementing institutional controls and local ordinances prescribing the circumstances under which intrusive activities can be performed.

The only other potential for impact from the presence of DNAPL is the dissolution of the DNAPL from the aquifer matrix beneath and adjacent to these disposal sites. Plume migration projections performed as part of the Sauget Area 1 Engineering Evaluation/Cost Analysis and Remedial Investigation/Feasibility Study (i.e., the EE/CA and RI/FS Report) indicate that mobile constituents from Site I could reach the Mississippi River, which is 5500 feet from Site I. Results from particle-track modeling (see Figure 1) indicate that, with the exception of groundwater from the very northern portion of Site I, impacted groundwater migrating from Sites G, H, I and L, Dead Creek Segment B north of Site M, Sauget Area 2, and other Sauget facilities will be captured by the Sauget Area 2 Interim Groundwater Remedy, which is currently being installed. When completed, the Sauget Area 2 Interim Groundwater Remedy will abate surface water impacts resulting from groundwater discharge to surface water downgradient of Sauget Area 2 Sites O, Q (Dog Leg), R and S; Sauget Area 1 Sites G, H, I and L; Dead Creek Segment B north of Site M; the W.G. Krummrich plant and other industries in the Sauget area.

ARARs - Dissolution of DNAPL trapped in the aquifer matrix currently exceeds Illinois Class I Groundwater Standards and will continue to do so in the future, .i.e. ARARs are now and will continue to be exceeded. Time to clean estimates made as part of the Sauget Area 1 EE/CA and RI/FS Report (see Section 3.0 of this Work Plan, "Previous Source Evaluation Study") indicate that Illinois Class I groundwater standards would be achieved in 488 years with no action and in 441 years with aggressive pumping at a flow rate of 1500 gpm. Planning-level calculations by GSI suggest that a DNAPL mass removal of 99.97% could be needed to achieve ARARs within 5 years and a mass removal of 99.96% could be needed to achieve ARARs in 30 years. Key assumptions for these calculations are i) an assumed starting source mass of 410,000 kg of DNAPL; and ii) changes in COC concentrations in groundwater are directly proportional to changes in DNAPL mass in the aquifer matrix.

Basis for Investigation - Based on this Conceptual Site Model (Figure 4), the DNAPL Characterization and Remediation Study is focused on collecting the information needed for i) estimation of the volume of DNAPL-affected material; ii) assessment of the ability to remove DNAPL from the aquifer matrix by treatment; iii) estimation of the removal efficiencies of various treatment technologies; and iv) determination of the presence of pooled DNAPL. These data will be used to determine if aggressive source treatment will make any meaningful difference in the time required to achieve ARARs and, if so, the cost of such treatment.

3) **Section 4.0 Task 4: Soil Sampling and Installation of Piezometers: The inclusion of a minimum of 3 and potentially up to 15 locations for soil sampling and piezometer installation represents a substantial increase in the ability of the proposed work to address questions regarding the lateral and vertical extent of DNAPL contamination at Sauget Area 1. A significant concern of USEPA is the potential extent of DNAPL contamination outside the boundaries of the fill areas. For example, Figures 2 and 3 of the revised work plan both indicate a potential for DNAPL to be present downgradient of Site I, possibly as far as Route 3. Figure 2 is based on Table 4-0c prepared on the basis of field notes which Solutia has suggested in previous conversations are not reliable, although no description of the deficiencies in these observations has been provided. Figure 3 was prepared by the PRP's consultants and represents their interpretation of the potential DNAPL extent based on a general "1% of solubility" rule of thumb.**

The proposed work should include an evaluation of the extent of potential DNAPL contamination outside the fill areas in Sauget Area 1. No more than 3 additional borings beyond those proposed in the revised work plan should be required to adequately evaluate the extent of DNAPL contamination outside the fill areas. This would increase the total number of new borings and piezometers from 15 to a maximum of 18, with a likely minimum of

6. It is possible that one or more of the 12 borings planned for the fill areas could be relocated locations outside the fill area depending on the outcome of the Task 2 DNAPL and LNAPL survey, which would reduce the total number of borings accordingly. The additional information is necessary to evaluate the possible volume of material requiring treatment and to assess the residual conditions that would exist should a TI waiver be the selected approach.

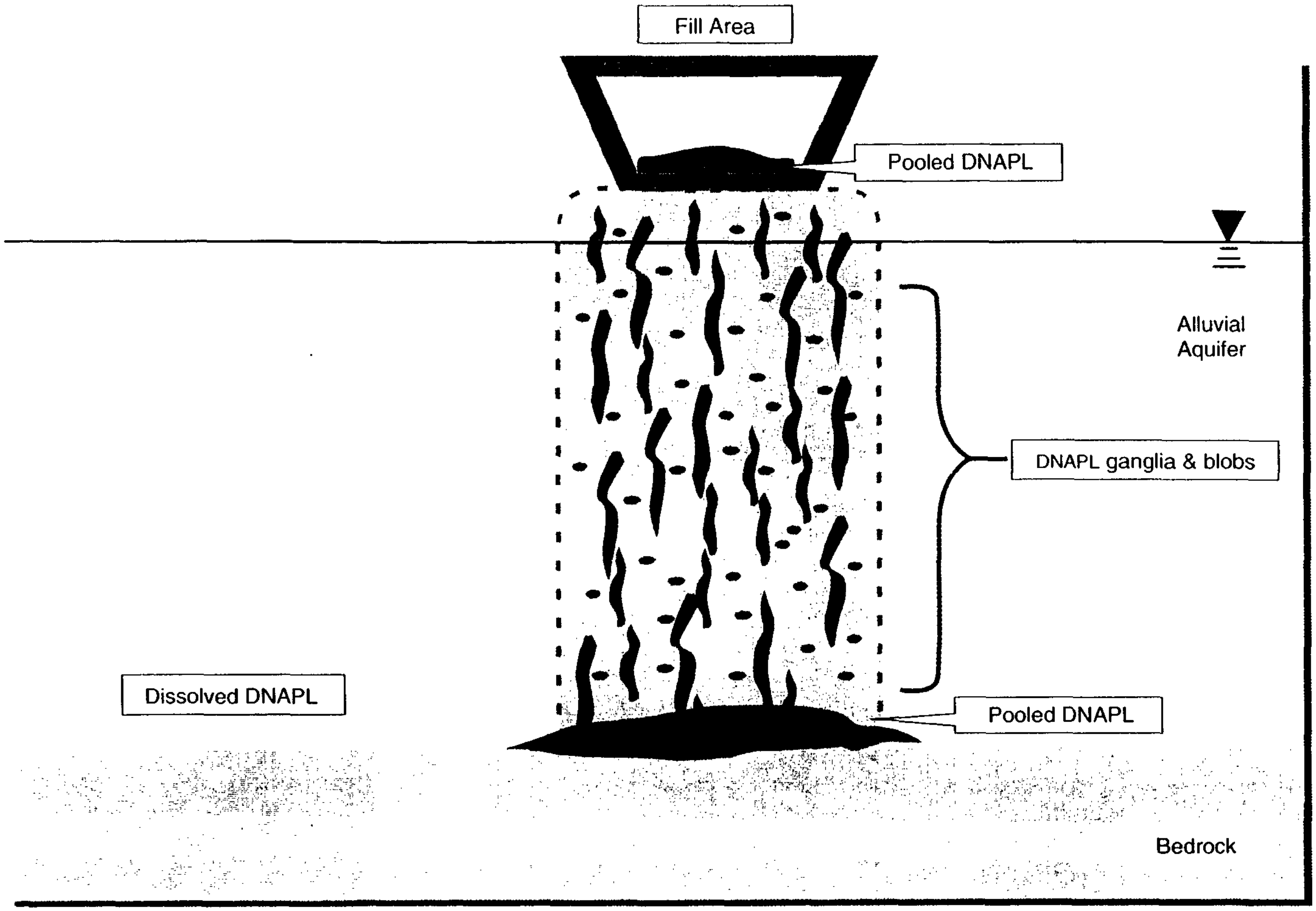
RESPONSE: Task 4 - Soil Sampling and Installation of Piezometers will be modified as indicated below to include up to three soil sampling locations outside of the fill areas and incorporated verbatim into the Work Plan:

Task 4: Soil Sampling and Installation of Piezometers

Goals of Task 4: The goals of Task 4 are i) to characterize the nature and extent of residual and free-phase DNAPL potentially present within the fill areas and within the upper, middle, and deep hydrogeologic units underlying the fill areas; ii) to investigate for the possible presence of pooled DNAPL in topographic lows on the bedrock surface; and iii) to evaluate the potential extent of residual and free-phase DNAPL outside the boundaries of the fill areas.

Proposed Number of Soil Sampling and Piezometer Locations: Soil sampling and piezometer installation will be conducted at up to 18 locations (see discussion in the paragraph below). Twelve of the soil boring and piezometer locations (three each at Sites G, H, I, and L) are primarily intended for characterizing the nature and extent of DNAPL within the waste materials and underlying hydrogeologic units. These borings will be within the fill areas at locations near the north, south, and west boundaries of the fill areas. Another three soil boring and piezometer locations are primarily intended for investigation of topographic lows in the bedrock surface (i.e., to determine whether pooled DNAPL is present in the topographic lows). These three locations will be selected based on results of the seismic reflection survey (Task 3). The final three soil boring and piezometer locations are primarily intended for evaluating the potential extent of DNAPL outside the boundaries of the fill areas. These three locations will be selected following completion of the initial DNAPL and LNAPL survey and recovery tests (Task 2).

Possible Reduction in Scope of Task 4 Depending on Results of Task 2: According to Table 4-0c, free phase NAPL is reported to be widespread and present at locations well beyond the boundaries of Sites G, H, I, and L. If results of the NAPL survey and recovery tests included in Task 2 confirm that NAPL is as widespread as reported in Table 4-0c, then the large volume estimates for DNAPL-containing waste materials and underlying aquifer that are discussed in the Conceptual Site Model (see Section 2.0) will have been confirmed. In this case, there may not be a need to further characterize the nature and extent of DNAPL at one or more of the Sauget Area 1 sites. Immediately following completion of the NAPL survey and recovery tests in Task 2, a determination will be made, in consultation with EPA, regarding how many soil boring and piezometer locations are appropriate for Task 4. At a minimum, Task 4 will include soil sampling and piezometer installation at the following locations: i) three proposed locations that are primarily intended for investigation of topographic lows in the bedrock surface; and ii) three proposed locations that are primarily intended for evaluating the potential extent of DNAPL outside the boundaries of the fill areas.



GROUNDWATER SERVICES, INC.	GSI Job No. G-2561	Drawn By: CRW	**CONCEPTUAL SITE MODEL OF DNAPL DISTRIBUTION**
	Issued: 10/31/03	Chk'd By: JAK	Solutia Inc.
	Scale: Not to Scale	**FIGURE 4**	Sauget Area 1, Sauget and Cahokia, Illinois

1. As requested, assumptions concerning the relationship between changes in aqueous-phase contaminant concentrations and DNAPL mass used in the referenced document have been reviewed by Dr. Daniel Pope of Dynamac Corporation. Dynamac Corporation is an off-site contractor providing technical support services to this laboratory. The concept that "changes in COC concentrations in groundwater are directly proportional to changes in DNAPL mass in the aquifer matrix" is stated several times in the workplan. This generalization is used, along with several other generalizations (*e.g.*, the assumption of uniform source concentrations across the source zone) to develop a conceptual model for facilitating estimates of contaminant removal rates and timeframes for remediation. The following comments regarding this assumption are provided for your consideration.

   It is clear from theoretical models and laboratory and field research that dissolved contaminant concentrations in ground water are not *necessarily* directly proportional to the NAPL mass in the subsurface media. For instance, dissolved contaminant concentrations in ground water may reach an upper limit (based on maximum water solubility of the pure phase contaminant, or, for mixed NAPLs, based on the mole fraction of the given contaminant in the NAPL and water solubility), and, therefore, increased amounts of NAPL would not increase the dissolved concentration of the contaminant proportionally at equilibrium. Also, decreased amounts of NAPL may be associated with increased dissolved contaminant concentrations under certain conditions (*e.g.*, as the NAPL/ground-water interfacial area changes with time during dissolution of the NAPL under dynamic conditions).[1] In addition, ground water could be very near NAPL, but not in direct contact or communication with the NAPL, and possibly have no dissolved contaminants derived from the NAPL.

   However, it appears that the conceptual model proposed in the *Workplan* and *Study* would at least provisionally justify use of the concept that "changes in COC concentrations in groundwater are directly proportional to changes in DNAPLs mass in the aquifer matrix," based on the following considerations. The proposed conceptual model appears to be based on the concept of a "box" of subsurface material, where DNAPL may be found in pools and at residual saturation in blobs and ganglia. The DNAPL is being dissolved and removed in ground water as the ground water flows through and out of the "box." In the conceptual model, the contaminant concentration in ground water moving out of the "box" is assumed to be that of the "source concentration" (*i.e.*, the average dissolved contaminant concentration in a vertical plane, transverse to ground-water flow, just downgradient of the DNAPL source material). The "source concentration" plane idea is derived from the approach used in the Domenico solution to model contaminant transport and fate. The user's manual for the BIOSCREEN software provides a simple explanation of this idea.[2] While the dissolved contaminant concentration over time at any one point on the plane may not be directly proportional to changes in the upgradient NAPL mass (*e.g.*, the contaminant concentration at a given point might remain at the maximum solubility for an extended time), it may be reasonable to assume for estimation purposes that the average concentration across the entire plane may vary proportionally to the upgradient NAPL mass in the entire "box."

   In addition, the averaging effects due to diffusion, dilution, dispersion and sampling with long well screens may tend to align the measured dissolved contaminant concentration with remaining NAPL mass in the "box" more than would be noted for the dissolved concentration that could be found in one small, defined flowpath. Also, the approach has some similarities to the approach used in the calculation of "Concentration vs. Time Attenuation Rate Constants," which have been used to estimate plume lifetimes at a given sampling location, and, therefore, indirectly to estimate the source lifetime (*i.e.*, a dissolved concentration is used to estimate source properties).[3] Nevertheless, the assumption as stated ("changes in COC

concentrations in groundwater are directly proportional to changes in DNAPLs mass in the aquifer matrix") is subject to significant possibility of error, and should be used with caution. This evaluation is limited to an assessment of the plausibility of the indicated part of the conceptual model (*i.e.*, "changes in COC concentrations in groundwater are directly proportional to changes in DNAPL mass in the aquifer matrix."), and is not intended to review any potential effects on remedy evaluation. Because the remediation comparisons and recommendations set forth in the Workplan and Study are based on calculations of the time necessary for dissolution to remove NAPL mass, and the proportionality assumption may strongly affect the results of such calculations, it is recommended that the workplan or final report fully discuss and evaluate the reasons for using the assumption, and provide alternative approaches to estimating NAPL removal for comparison.

References

1) Wiedemeier, T.H., et al. *Natural Attenuation of Fuels and Chlorinated Solvents In The Subsurface.* 1999. John Wiley & Sons, NY. "Attenuation of Source Zones and Formation of Plumes." Page 97.

2) BIOSCREEN Natural Attenuation Decision Support System User's Manual. Version 1.3. June 1996. United States Environmental Protection Agency, Office of Research and Development. Washington DC 20460. EPA/600/R-96/087. August 1996.

3) Newell, C.J. et al. Calculation and Use of First-Order Rate Constants for Monitored Natural Attenuation Studies. November 2002. Ground Water Issue. EPA 540/S-02/500.

RESPONSE: Solutia believes it is imperative to "fully discuss and evaluate the reasons for using the assumption [that changes in COC concentrations in groundwater are directly proportional to changes in DNAPL mass] and provide alternative approaches to estimating DNAPL removal comparison" in the Work Plan rather than in the Final Report. Time to clean estimates are a critical component of the comparative analysis of remedial alternatives that will be performed for the Final Report. The model used to make a time to clean estimate for each of the remedial alternatives needs to be determined in advance of performing the work to ensure an effective and objective comparative analysis of remedial alternatives.

Predicting DNAPL source zone response is an active research area and current research is summarized in the attached Technical Memorandum "Applicability of Uniform Concentration to Mass Ratio Assumption". Some research indicates that a large volume of DNAPL mass removal is required to achieve a small reduction in DNAPL dissolution (flux). Other research indicates that a small volume of DNAPL removal can achieve a large reduction in DNAPL dissolution. The model used in the Sauget Area 1 Source Evaluation Study is based on the assumption that dissolved groundwater concentrations are directly proportional to DNAPL reductions, which is supported by research performed by Newell et al. (1996).

As can be seen in Figure 1 of the Technical Memorandum, the model assumption used in the Sauget Area 1 Source Evaluation Study will result in time to clean predictions that are roughly midway between time to clean predictions based on the low DNAPL mass removal/high flux reduction assumptions of Rao and Jawitz (2003) and Enfield et al. (2002) and the high DNAPL mass removal/low flux reduction assumptions of Rao et al. (1997) and Sale and McWhorter (2001). For this reason, it is considered appropriate to use the Sauget Area 1 DNAPL Dissolution Model (as described in the Source Evaluation Study) in Task 8 - Remedial Alternatives Evaluation of the DNAPL Characterization and Remediation Study.

To address this issue, Section 8.0 Remedial Alternatives Evaluation will be expanded as shown below and incorporated verbatim in the Work Plan:

Task 8: Remedial Alternatives Evaluation

An updated evaluation of remedial alternatives for Sauget Area 1 will be performed based on the findings from Tasks 2 through 7 of this work program and results of previous remedial alternative analyses documented in earlier site reports. The evaluation will result in a comparison of the costs, benefits, and engineering considerations of the following remedial alternatives:

- Natural Attenuation (from Sauget Area 1 EE/CA and RI/FS Report).
- Capping Source Areas (from Sauget Area 1 EE/CA and RI/FS Report).
- Physical Barrier at Mississippi River (from Sauget Area 1 EE/CA and RI/FS Report, Sauget Area 2 Interim Groundwater Remedy FFS, and capture zone modeling of the Sauget Area 2 Interim Groundwater Remedy using a particle tracking model).
- Aggressive Pump-and-Treat at Sauget Area 1 Source Areas (Sites G, H, and I) (from Sauget Area 1 EE/CA and RI/FS Report).
- In-Situ Treatment of Source Areas and Aquifer Matrix (for the most promising source depletion alternative identified in Tasks 6 and 7 of this work program).

A simple source model, originally developed as part of the BIOSCREEN model (Newell et al., 1996, EPA/600/R-96/087) and now being included as part of the BIOCHLOR model (Aziz et al., 2000 (EPA/600/R-00/008), was used to estimate the lifetime of the groundwater source at Sauget Area 1 Site I under different remediation options in the Sauget Area 1 EE/CA and RI/FS Report (see Attachment 2 - Sauget Area 1 Source Evaluation Study, May 21, 2001).

In this simple box model, the source zone is considered to be located in a box containing some mass of dissolvable contaminants. The rate at which contaminants leave the box is estimated from the rate at which flowing groundwater removes contaminants from the box. The time required to achieve a cleanup standard can then be estimated by comparing the mass of contaminants in the box vs. the time to remove contaminants from the box. To more closely match real site conditions, the source concentration is assumed to decay over time in proportion to the remaining source mass (Wiedemeier et al., 1999).

Predicting DNAPL source zone response is an active research area and current research is summarized in the Technical Memorandum "Applicability of Uniform Concentration to Mass Ratio Assumption" (Attachment 3). Some research indicates that a large volume of DNAPL mass removal is required to achieve a small reduction in DNAPL dissolution (flux). Other research indicates that a small volume of DNAPL removal can achieve a large reduction in DNAPL dissolution. The model used in the Sauget Area 1 Source Evaluation Study is based on the assumption that dissolved groundwater concentrations are directly proportional to DNAPL reductions, which is supported by research performed by Newell et al. (1996).

As can be seen in Figure 1 of the Technical Memorandum, the model assumption used in the Sauget Area 1 Source Evaluation Study (changes in constituent concentrations in groundwater are directly proportional to changes in DNAPL mass) will result in time to clean predictions that are roughly midway between time to clean predictions based on the low DNAPL mass removal/high flux reduction assumptions of Rao and Jawitz (2003) and Enfield et al. (2002) and the high DNAPL mass removal/low flux reduction assumptions of Rao et al. (1997) and Sale and McWhorter (2001). For this reason, it is considered appropriate to use the Sauget Area 1 DNAPL Dissolution Model (as described in the Source Evaluation Study) in Task 8 - Remedial Alternatives Evaluation of the DNAPL Characterization and Remediation Study. This model will be used to make a time to clean estimate for each of the remedial alternatives to ensure an effective and objective comparative analysis of all of the remedial alternatives.

GROUNDWATER SERVICES, INC.

TECHNICAL MEMORANDUM

TO: Mr. Bruce Yare, Solutia Inc.

FROM: Chuck Newell, James Kearley, and Shahla Farhat

RE: Applicability of Uniform Concentration to Mass Ratio Assumption, Workplan for DNAPL Characterization and Remediation Study, Sauget Area 1, Sauget, Illinois

BACKGROUND

The Workplan for DNAPL Characterization and Remediation Study submitted by Solutia Inc. to the U.S. Environmental Protection Agency (U.S. EPA) included results from a Source Evaluation Study prepared by Groundwater Services, Inc. (see Appendix C in the Workplan). These results were summarized in the DNAPL Workplan as:

> *Planning-level calculations by GSI suggest that removal of 99.97% or 99.96% of the DNAPL mass could be needed to achieve ARARs within 5 years or 30 years, respectively. The key assumptions for these calculations were i) an assumed starting source mass of 410,000 kg of DNAPL; and ii) changes in COC concentrations in groundwater are directly proportional to changes in DNAPL mass in the aquifer matrix.*

In response, the U.S. EPA commented on the assumption that concentrations in groundwater are directly proportional to changes in DNAPL mass:

> *"... it is recommended that the workplan or final report fully discuss and evaluate the reasons for using the assumption, and provide alternative approaches to estimating NAPL removal for comparison."*

We appreciate the insightful comment from the U.S. EPA, since predicting DNAPL source zone response is currently a critical remediation issue, and is an active research area in which Groundwater Services, Inc. is participating. Predicting source zone response was discussed in detail during C. Newell's work on the EPA's Expert Panel on DNAPL Source Depletion. Groundwater Services, Inc. (GSI) is now charged with developing tools to transfer the current state of knowledge regarding source zone response as part of a Strategic Environmental Research and Development (SERDP) research grant. (This project is known as the Decision Support System to Evaluate Effectiveness and Cost of Source Zone Treatment).

SOURCE DECAY MODELING PROCEDURES

The source decay model used for the Sauget Area 1 Source Evaluation Study was originally presented in the BIOSCREEN model (Newell et al, 1996). Since that time there has been an increased focus on the relationship between concentration (and mass flux) vs. DNAPL mass.

Sale and McWhorter (2001) developed a multiple analytical source superposition technique (MASST) where a heterogeneous DNAPL architecture was conceptualized as a series of discrete subzones containing DNAPL (i.e., fingers and pools) separated by portions of the aquifer entirely free of DNAPL. The groundwater flow field was considered to be uniform. Using the MASST model, Sale and McWhorter concluded that "remediations that reduce DNAPL saturations will have little effect on near-term groundwater quality" and that "removal of the vast majority of the DNAPL will likely be necessary to achieve significant near-term improvements in groundwater quality."

However, other research by Rao and Jawitz (2003) and by Rao et al. (2001) reached a different conclusion: "We contend that in heterogeneous formations, significant contaminant flux reductions can be realized through partial mass reduction in DNAPL source zones." (Rao and Jawitz, 2003).

These different source response models were summarized by Stroo et al., (2003) using curves that show concentration reduction (in the form of mass flux reduction) vs. source mass reduction. In a modified version of their presentation, the results from Sale and McWhorter (2001) are plotted as the curve no. 5 in Figure 1. Source mass reductions of greater than 80% are required to reduce source concentrations (i.e., mass flux) more than 10%. However, theoretical results from Enfield et al., (2002) and Rao and Jawitz (2003) (curves 1 and 2) show that for a given reduction in source mass, a larger reduction in mass flux results. For example, the Rao and Jawitz curve no. 1 shows that a 40% reduction in source mass would yield a 75% reduction in mass flux.

Note that curve 3 represents the case where source mass reduction causes an equivalent reduction in mass flux. In other words, curve 3 reflects the assumption that concentrations in groundwater are directly proportional to changes in DNAPL mass (if there is no change in the groundwater flow field before and after remediation). This was the assumption that was used in the Sauget Area 1 Source Evaluation Study and was referenced in the DNAPL Workplan.

It is our opinion that the source zone assumption referenced in the DNAPL Workplan represents the middle ground in a research area where at present there is no widely accepted approach or model. For example, Stroo et al. (2003) concluded that the "ability of source removal technologies to improve groundwater quality and reduce overall plume management costs is controversial." An Expert Panel convened by EPA (report in press) has concluded that there is considerable uncertainty regarding the relationship

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between source mass reduction and the reduction in mass flux from the source zone. (C. Newell was a member of this Expert Panel).

Rather than present widely different models for source response in the DNAPL Workplan, some which would show dramatic changes in concentration and some which would show almost no changes in concentration, we suggest that the DNAPL Workplan retain the existing source response model. This model represents the "middle ground" of current approaches and should provide results that are adequate for "planning level calculations" for evaluating how various remediation approaches might affect the remediation timeframe for Sauget Area 1.

C. Newell, J. Kearley, and S. Farhat

REFERENCES

Enfield, C. G.; Wood, A. L.; Brooks, M. C.; Annable, M. D, 2002. Interpreting tracer data to forecast remedial performance. In *Groundwater Quality: Natural and Enhanced Restoration of Groundwater Pollution,* Thornton, S. Oswald, S., Eds., IAHS: Sheffield, United Kingdom, 2002; pp 11-16.

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Sale, T.C. and McWhorter, D.B. 2001. Steady State Mass Transfer from Single-Component DNAPLs in Uniform Flow Fields. *Water Resources Research*, 37(2), 393-404.

Stroo, H. F., M. Unger; C. H. Ward; M. C. Kavanaugh; C. Vogel; A. Leeson; J. A. Marqusee; B. P. Smith, 2003. Remediating *Chlorinated Solvent* Source Zones, Environmental Science & Technology, Volume 37, No. 11, page 225A – 230A.

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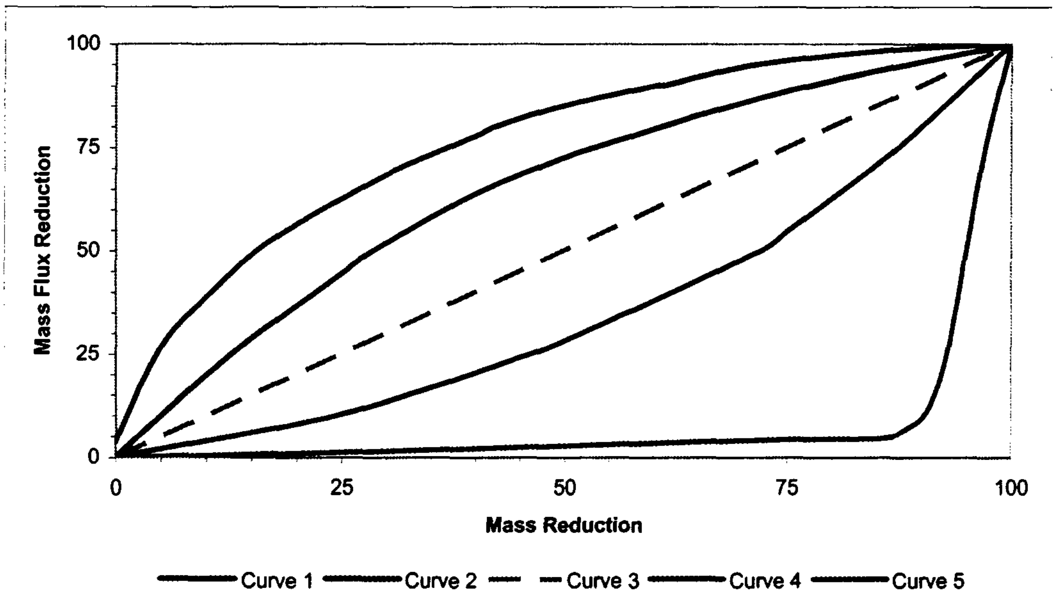

Figure 1. Different Flux Reduction vs. Mass Reduction Curves. The dashed curve (Curve 3) was used for the Sauget Area 1 Source Evaluation Study.

Sources: Curve 1 (top curve): Rao and Jawitz, 2003;

Curve 2: Enfield et al., 2002;

Curve 3: Newell et al., 1996;

Curve 4: Rao et al., 1997;

Curve 5 (bottom curve): Sale and McWhorter, 2001.

Note that mass flux reduction is equivalent to average concentration reduction in the case where the groundwater flow field does not change.